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1. Your reference	NJH/MP6107643	
2. Patent application number *(The Patent Office will fill in this part)*	0225791.3	05 NOV 2002
3. Full name, address and postcode of the or of each applicant *(underline all surnames)* Patents ADP number *(if you know it)*	KRATOS ANALYTICAL LIMITED WHARFSIDE TRAFFORD WHARF ROAD MANCHESTER M17 1GP 557579002	
If the applicant is a corporate body, give the country/state of its incorporation	GB	
4. Title of the invention	CHARGED PARTICLE SPECTROMETER AND DETECTOR THEREFOR	
5. Name of your agent *(if you have one)*	MEWBURN ELLIS	
"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	YORK HOUSE 23 KINGSWAY LONDON WC2B 6HP	
Patents ADP number *(if you know it)*	109006	

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and (if you know it) the or each application number

Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

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Description	19
Claim*(s)*	0
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10. If you are also filing any of the following, state how many against each item

Priority documents	0
Translations of priority documents	0
Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	0
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Request for substantive examination *(Patents Form 10/77)*	0
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11. I/We request the grant of a patent on the basis of this application.

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Date
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12. Name and daytime telephone number of person to contact in the United Kingdom — NIGEL J. HACKNEY — 0161 247 7722

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CHARGED PARTICLE SPECTROMETER AND DETECTOR THEREFOR

The present invention relates to a charged particle spectrometer and to a method of operation of such a spectrometer. In particular, the present invention relates to a detector for such a spectrometer.

The bulk of the specification describes the application of the invention in a photoelectron spectrometer, but other charged particle instruments would also be suitable. For example, a hemispherical only analyser system where the input lens system is operated in such a way as to project a line image from the specimen that is then dispersed in the orthogonal direction to generate a 2 d image with one axis being position along a line on the sample and the other photoelectron energy. Alternatively, the input lens system could be operated to project an angular distribution from the sample as in a VG theta probe.

A current photoelectron spectrometer produced by the applicant is shown schematically in Figure 1. The

instrument consists of a magnetic lens 2 above which is located the sample 4 to be analysed. In use, the sample 4 is bombarded by X-rays from an X-ray source 6 and the photoelectrons produced are passed through a charge neutraliser 8 and an electrostatic lens system 10 so as to be focused at an entry 12 to an energy analysing section 14.

The instrument has two modes of operation: a spectrum mode for analysing the composition of the surface of the sample 4; and an imaging mode for producing a magnified energy selected photoelectron image of the surface of the sample 4. In the spectrum mode, the photoelectrons pass through a hemispherical analyser 16 and are received by a pair of detectors 18, 20, which are groups of channeltrons. The two groups of channeltrons enable the instrument to produce an energy spectrum relating to the composition of the surface of the sample 4 from which that composition can be analysed.

In imaging mode, the photoelectrons pass through spherical mirror analyser portion 22 of the energy analysing section 14 and are received by a different detector 24 which is a micro channel plate (MCP) detector. Photo electrons received by the micro channel

plate are used to produce further secondary electrons which are then projected on to a phosphorescent screen. The phosphorescent screen can then be viewed by a CCD camera from which an energy analysed photoelectron image of the surface of the sample 4 can be produced. Said image could represent the distribution of a particular element or chemical state of the element.

This instrument has the disadvantage that two types of detectors are required as explained above, one for each mode of operation. The present invention aims to reduce or overcome some or all of the disadvantages associated with prior art instruments.

Accordingly, in a first aspect, the present invention provides a photoelectron spectrometer which is operable in a first mode to produce an energy spectrum relating to the composition of a sample being analysed, and in a second mode to produce an image (e.g. a photoelectron or other charged particle image) of the surface of the sample being analysed, wherein the spectrometer includes a detector which is used to detect photoelectrons produced in both modes of operation.

In this way, the present invention reduces the complexity of the detector system of the prior art instrument. Also the detector means can receive photoelectrons over a larger physical area than is the case with the prior art since in the prior art since the two types of detector can not be located in the same physical location and so each detector in use is only covering a part of the detection area.

Preferably the detector means includes plate means (such as a micro channel plate) on to which in use primary electrons are directed in both modes of operation and which emits a plurality of secondary electrons for each primary electron received. Preferably the detector means also includes first delay line means for using the plurality of secondary electrons to produce a pair of electrical pulses in a delay line from which a signal processing means can calculate the location of the primary electron on the plate means in a first direction. More preferably, the detector means also includes second delay line means for using the plurality of secondary electrons to produce a pair of electrical pulses in a second delay line from which the signal processing means can calculate the location of the primary electron on the plate means in a second direction.

Effectively, this type of detector means partly replaces the phosphorescent screen and CCD detector as described in the prior art. This enables the location of each primary electron on the plate means to be determined more accurately.

Preferably the first and second directions are orthogonal e.g. effectively define an X and Y axis on the plate means.

In some embodiments the spectrometer includes signal processing means for processing the signals received from one or both of the delay lines in order to reduce or eliminate any unwanted signals, such as noise caused by imperfections in the construction of the detector and/or electronic cross talk between the delay lines.

Preferably the spectrometer includes control means for controlling its operation and enabling a user to select which of the two modes is operating. Preferably the control means also controls the signal processing means such that when the spectrometer is operating in spectrum mode, the signal processing means utilises signals from only one of the delay line means.

Additionally or alternatively, the control means may also control the signal processing means so that when the spectrometer is operating in image mode the signal processing means utilises signals from both the first and second delay line means and may also include further processing means for increasing the accuracy of the time measurements of the electrical pulses, preferably by stretching the time between each one of a pair of pulses so that the time difference may be more accurately measured.

In a further aspect, the present invention provides a detector for a photoelectron spectrometer, the detector including any or all of the features described above.

In a further aspect, the present invention provides a method of operating the photoelectron spectrometer as described above wherein the method includes the step of selecting which of the two modes to use and the detector means being operated accordingly.

An embodiment of the present invention will now be described with reference to the accompanying drawings in which:-

Fig. 1 is a schematic diagram of a prior art photoelectron spectrometer.

Fig. 2 is a schematic diagram of a photoelectron spectrometer according to the present invention.

Fig. 3 is a schematic diagram showing part of a detector according to an embodiment of the present invention.

Fig. 4 is a flow chart showing the operation of a spectrometer according to an embodiment of the present invention.

Fig. 5 is a schematic diagram showing the operation of a detector according to an embodiment of the present invention in spectroscopy or spectrum mode.

Fig. 2 shows a schematic diagram of an XPS (X-ray photoelectron spectrometer) which in its basic operation is fairly similar to the instrument shown in Fig. 1. Identical reference numerals have been used for those parts of the instrument which are the same. The main differences lie in the detector used.

In Fig. 2, the spectrometer includes a single detector unit 30 which is usable in both modes of operation of the spectrometer - spectrum mode and imaging mode. In some embodiments, the detector plate 30 is a

micro channel plate (MCP) and in some other embodiments it may include a plurality of micro channel plates, such as three or more plates.

Arranged adjacent to the detector plate 30 is a pair of delay lines 32, 34, although more or fewer delay lines may be used. The detector plate 30 and the delay lines 32, 34 together make up the detector of this instrument and this detector is usable for both imaging and spectroscopy, unlike the prior art instrument described above.

Fig. 3 shows in schematic form the operation of part of the detector. In use, in either mode of operation, primary electrons from the instrument will strike the micro channel plate (MCP) 40. In Fig. 3, a single electron 42 is schematically shown striking the micro channel plate 40. The operation of the detector plate, such as an MCP, is to amplify a single electron by a large factor (e.g. 10^7) to produce a "shower" 44 of secondary electrons. A delay line 46 is arranged in a suitable position so that the shower 44 of electrons may fall on it or strike it. As shown in this embodiment, the delay line 46 is arranged such that it covers all or substantially all of the area of the detector plate and

also preferably such that the line is laid out in a serpentine fashion whereby the elongate parts of the line are parallel or substantially parallel. However, other arrangements of the delay line may be possible.

In this way, the elongate parts of the delay line 46 may be arranged to lie on or parallel to a chosen axis of the detector plate. In this example, the delay line lies parallel to what is shown as the "X" axis and so the delay line is called the "X" delay line.

The function of the delay line is such that the shower of secondary electrons striking it produces a pair of pulses 48, 50 which propagate in respectively different directions along the delay line i.e. one pulse 50 propagates towards a first end 52 and the second pulse 48 propagates towards a second end 54. The ends of the delay line may be connected to signal processing means which receives the pulses 48, 50 and calculates the time difference between their times of receipt, shown schematically in Fig. 3. This time difference enables the point or origin 56 of the shower 44 on the delay line 46 to be calculated, or at least its coordinate in the "X" direction. This correlates to the position at which the primary electron 42 struck the detector plate and so

the position of that electron in the "X" direction can be determined.

In some of the embodiments, the detector may include a second delay line which functions as described above but is laid out in a different way. Preferably the second delay line is laid out so that its elongate parts lie along or parallel to a different axis to the "X" axis and more preferably that different axis is orthogonal to the "X" axis e.g. the "Y" axis shown in Fig. 3. In this way, the position of the primary electron 42 may be determined with respect to both axis i.e. its precise location on the detector plate can be known if necessary depending on the mode of operation of the spectrometer.

The spectrometer of one aspect of the present invention may be operable in either one of two different modes as mentioned above - a spectrum mode and an imaging mode. Fig. 4 is a flow chart showing an overview of the operation in both modes. As can be seen, in spectrum mode only readings in only one dimension are required at the detector and so only a portion of the detector may be used. In the detector embodiment utilising a pair of delay lines as described above, this means that the signal processing means may operate on only signals

received from one of the delay lines e.g. the "X" delay line as shown in Fig. 3. This is also shown in more detail in Fig. 5.

Fig. 4 also shows the operation of the spectrometer in the imaging mode in which data from two dimensions on the detector is desired. In the detector embodiment described above utilising a pair of delay lines, this means that the outputs of both delay lines will be utilised by the signal processing means as previously described in order to determine the position of the primary electrons on the detector.

Fig. 5 shows schematically how a single delay line 60 is utilised to determine a measurement of the energy of photoelectrons falling on the detector plate. By the nature of the operation of the spectrometer, the further along the "X" axis at which an electron strikes the detector plate, the greater its energy. The delay line 60 is used as previously explained in order to determine the position of electron strike in this "X" direction. In this mode, one or more "time stretchers" may be used in order to enhance the time resolution available for calculating the time difference between pulses in a pair of pulses on each delay line.

A detailed embodiment of the detector electronics will now be described in order to illustrate the operation of both modes:-

The position of an electron impact on the detector is determined using an electronic system.

When an electron hits the front of the detector micro-channel plate (MCP) it causes a current pulse from the MCP power supply, as an avalanche of secondary electrons is created. The current pulse may be detected as a voltage pulse across a resistor. Preferably, after amplification, if the pulse exceeds a predefined threshold, an ECL (emitter coupled logic) "start" pulse is generated e.g. using a constant fraction discriminator circuit (CFD). The CFD may be used rather than a simple threshold detector so that the timing of the ECL signal is related to the peak of the voltage pulse, and is independent of the amplitude of the pulse.

The electron cloud leaving the back of the MCP hits the detector wire(s), and respective current pulses propagate to both ends of each detector wire. They are detected

e.g. as voltage pulses across resistors, may be amplified and preferably ECL "stop" pulses are generated using CFDs as before. The position of the electron impact on the detector can be determined by timing between the start pulse and the stop pulses, using the position measurement electronics. The difference between the two times for each wire indicates the distance of the impact position from the centre of the wire. The sum of the two times for each wire should be constant, and can be used to detect and reject overlapping impacts.

The position measurement electronics uses e.g. multi-channel time-to-digital converter (TDC) integrated circuits to measure the start to stop periods. The stop pulses are enabled into the circuitry by the arrival of a start pulse, to prevent spurious stop pulses causing invalid measurements. A timeout period may be used to reset the circuitry if the stop pulses are not received within the maximum start to stop duration. In this example, valid ECL signals are converted to positive ECL (PECL) and are passed to the TDC inputs. The TDCs are capable of timing start to stop periods to a 500ps resolution.

As described before, the electronics has two modes of operation: a single dimensional mode and a two dimensional mode. In the single dimensional mode the stop pulses from only one of the detector windings are used. In this mode the 500ps resolution of the TDC is sufficient, but a high TDC throughput is desired. This is achieved by multiplexing the start and stop pulses to each of a plurality e.g. four, TDCs in turn. While one device is timing an event, the other device(s) are at different stages of outputting their data to a FIFO, under the control of a hardware state machine. The times are then read from the FIFO into a digital signal processor (DSP) for processing.

In the two dimensional mode the signals from both detector windings are used. In this mode a resolution of 50ps is achieved using a time stretching circuit. In one example, a capacitor is charged to a set voltage, prior to operation of the time stretcher circuit. During the start to stop period the capacitor is negatively charged using a fixed constant current, such that the capacitor voltage crosses a threshold just below the initial voltage and continues to increase negatively until the end of the start to stop period. At the end of this period the capacitor is charged positively at a slower

rate using a lower constant current, back to the initial voltage. As the capacitor voltage crosses the threshold voltage, a high-speed comparator produces a stop signal, which is passed to the TDC. The amount the time is stretched is determined by the ratio of the discharging current to the charging current.

A lower throughput is required in two-dimensional mode, so the time stretching and the need to read four values out of the TDC rather than two, does not cause a throughput problem. It is also possible to use a single TDC in this mode to eliminate small timing offset differences, caused by manufacturing process differences between TDCs, which may otherwise be experienced.

It is possible that images captured using the delay line detector may contain distortions which appear as faint horizontal and vertical stripes. These are thought to be caused by imperfections in the construction of the detector and/or electronic cross talk between the four stop signals. The invention may use a calibration method which reduces these artefacts.

It is assumed that the stripes are caused by the detector system "moving" electron events slightly from their true

positions, depending on their positions in the image and that the error in the horizontal (X) position is independent of the vertical (Y) position and vice versa. Where the image is too bright, the electron events are moved away from each other and where the image is not bright enough, the electron events are moved closer together. Each electron event's position can be corrected independently for X and Y. The calibration consists of two tables containing a position adjustment for each X and Y position.

This procedure causes a slight loss of spatial resolution, but because adjustments are small the loss of resolution is small compared with the instrument resolution. There is no effect on image intensity, since the overall number of electron events remains the same.

The calibration tables are generated using a reference image obtained by uniformly illuminating the detector.

The procedure for generating the correction table for X positions of an image is described. The procedure for Y is identical. As an example, the image is assumed to be 500 points by 500. The reference image consists of a list of X and Y co-ordinates in the range 0-499. The total

number of electron events should be as large as is practical, typically several million.

1. The total number of electron events at each X position (regardless of Y position) is calculated, giving a array of 500 intensities. Each element represents the total intensity of a vertical line of the image.
2. The list of intensities is normalised by dividing each intensity by the average of all intensities and subtracting 1.0. This gives a list of positive and negative values close to zero and represents the error in intensity at each position.
3. The calibration table of position adjustments is derived as follows.

- The position adjustment for the first point (co-ordinate value 0) is set to half the intensity error for the first point.
- For all other points except the last, starting with the 2nd point and working up, the position adjustment is set to the position adjustment of the previous point added to the average intensity error of the previous and current points.
- For the last point (co-ordinate value 499) , the position adjustment is set to the position adjustment

of the previous point (co-ordinate value 498) added to half the intensity error of the last point.

The co-ordinates for each electron event are adjusted by adding the appropriate X position adjustment to the X co-ordinate and the appropriate Y position adjustment to the Y co-ordinate. This results in co-ordinates which are real numbers, not integers and some co-ordinates may be less than 0.0 or greater than 499.0.

Often, it is necessary to convert the co-ordinates to integers. Because the calibration corrections are typically less than 1.0, simply truncating or rounding the co-ordinates to integers would not give acceptable results. In order to convert the co-ordinates to integers an algorithm is used which rounds up or down at random, with the probability of rounding up depending on the magnitude of the fractional part. This is done by adding a random number between 0.0 and 0.9999999 to each co-ordinate and then truncating to an integer.

The above embodiments are intended to be an example of the present invention and variants and modifications of those embodiments, such as would be readily apparent to the skilled person, are envisaged and may be made

without departing from the scope of the present invention.

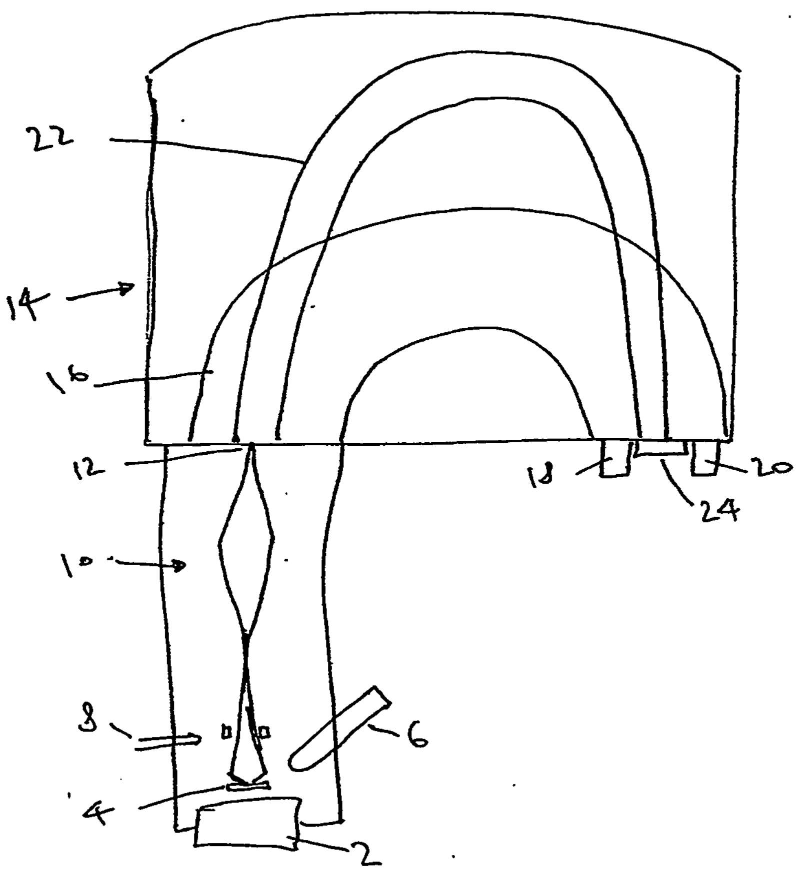

FIG 1

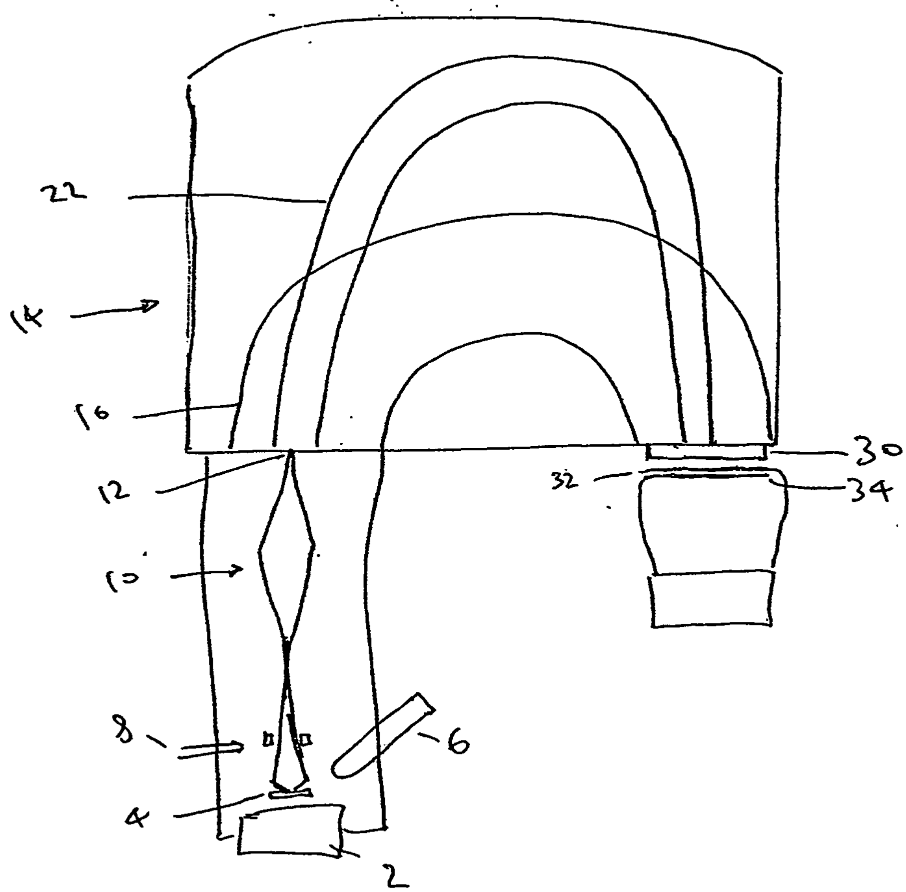

FIG 2

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Detector Technology

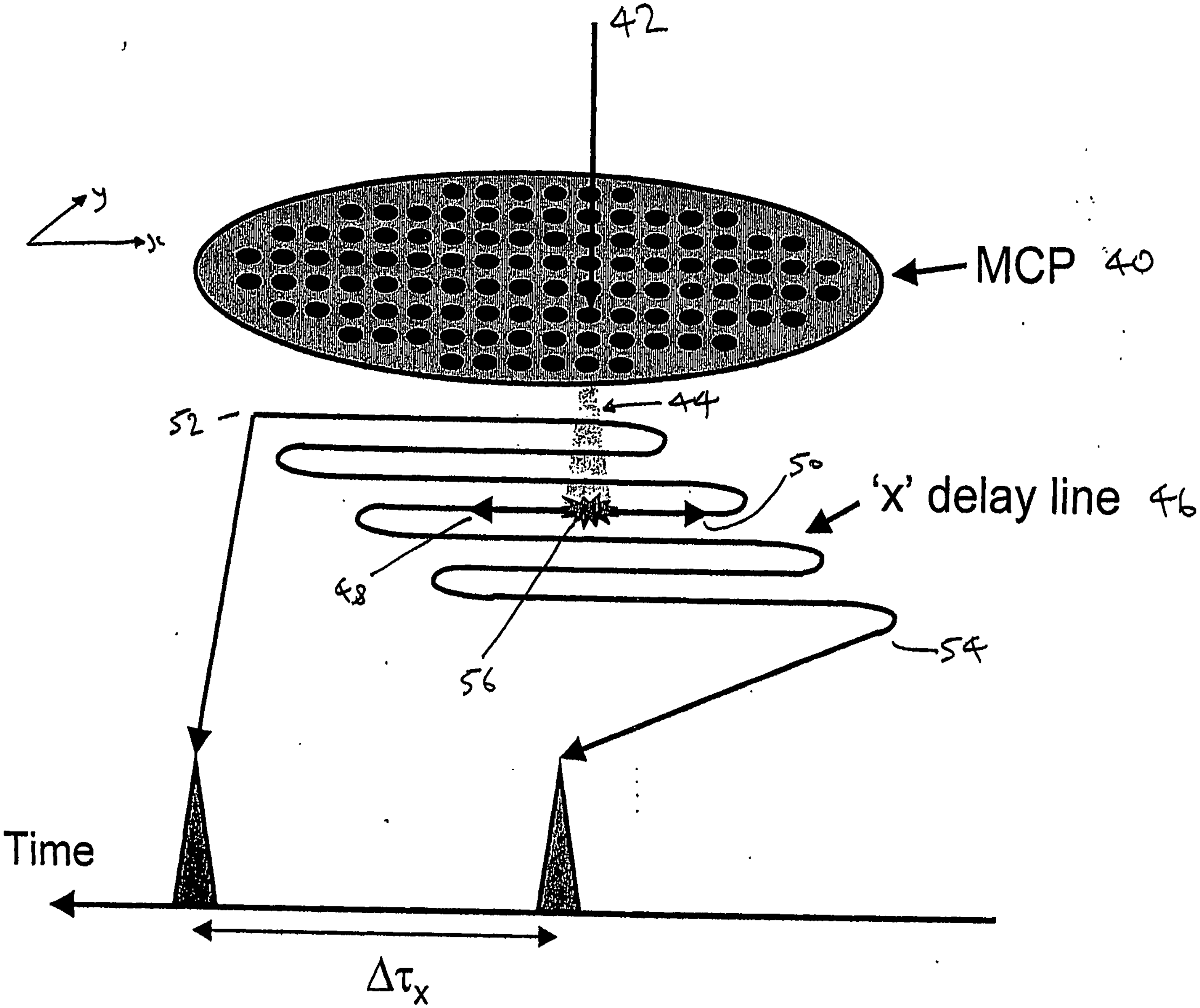

FIG3

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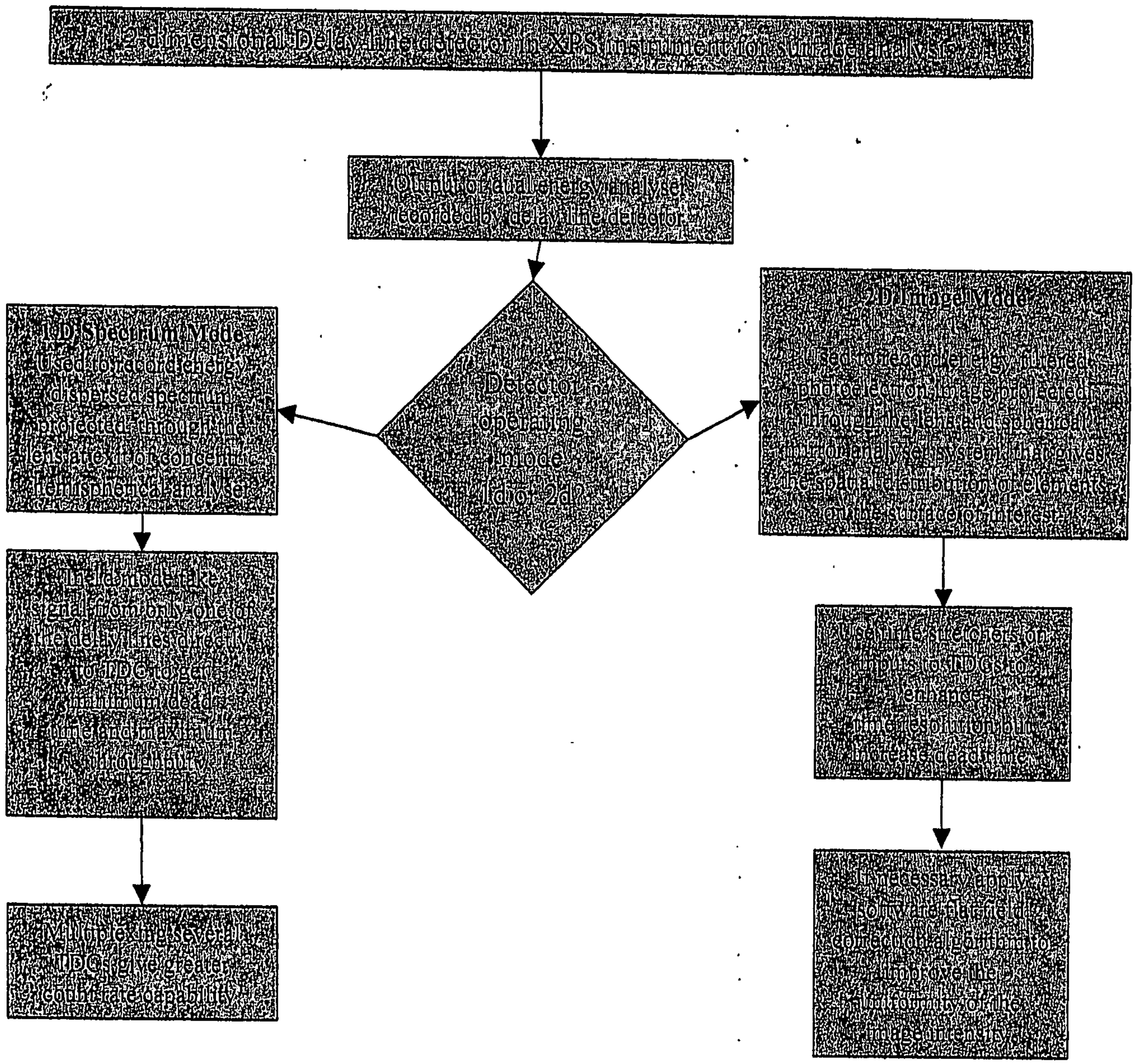

FIG 4

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Spectroscopy Mode

- In spectroscopy mode the photoelectron energy is dispersed across the detector in one direction only.

- Fast electronic counting gives a total of 128 pulse collecting channels resulting in high sensitivity and new modes of operation.

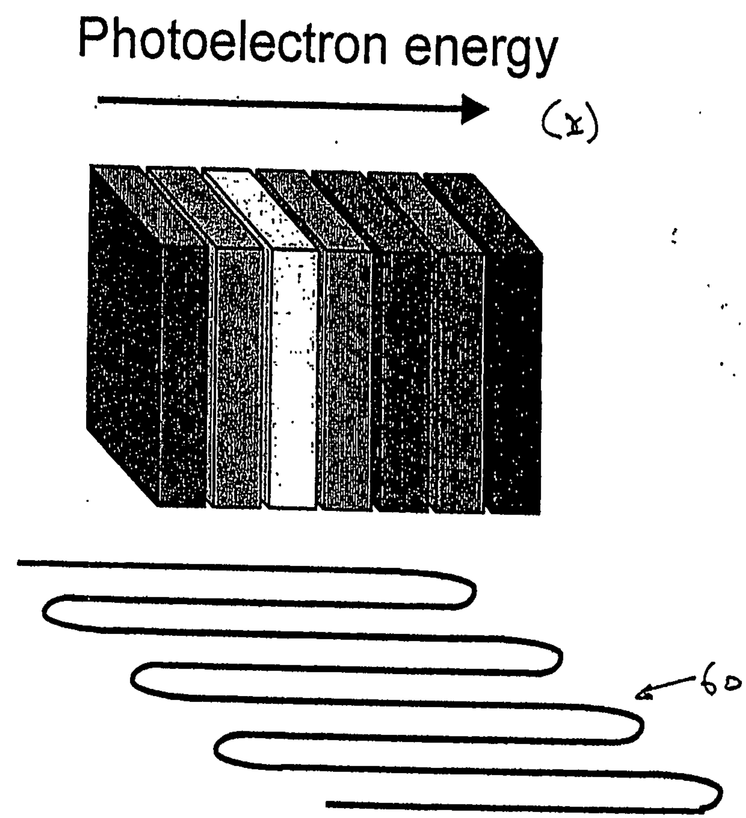

FIG 5

PCT Application
GB0304750